Δελτίο της Ελληνικής Γεωλογικής Εταιρίας, 2010
Πρακτικά 12ου Διεθνούς Συνεδρίου
Πάτρα, Μάιος 2010

Bulletin of the Geological Society of Greece, 2010
Proceedings of the 12th International Congress
Patras, May, 2010

ENGINEERING GEOLOGICAL AND GEOTECHNICAL INVESTIGATION OF LANDSLIDE EVENTS IN WILDFIRE AFFECTED AREAS OF ILIA PREFECTURE, WESTERN GREECE

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Abstract

In August 2007 Ilia Prefecture suffered one of the most devastating wildfires that have ever happened on European level. Approximately 870km², mainly forest and agricultural land, were lost, more than 60 people were killed, hundreds were injured and many villages suffered extensive damage. Heavy rainfall and human activities, favoured by the loss of vegetation and the overall susceptibility of geological formations in landsliding, induced the manifestation or reactivation of various scale landslide phenomena. In order to investigate and mitigate the problem University of Patras was commissioned by the Region of Western Greece to undertake an Engineering Geological and Geotechnical investigation. Site investigation accomplished in seven municipalities focusing on several landslide events with serious socio-economic impact and as a result many small scale cases were identified. In each one of these cases large scale engineering geological mapping was conducted and remedial and protection measures were designed.

Key words: *Wildfires, Landslides, Geotechnical Investigation, Ilia Prefecture, Western Greece*

1. Introduction

Few months after the devastating wildfires of August 2007 that affected Ilia Prefecture the University of Patras was commissioned by the Region of Western Greece to undertake an Engineering Geological and Geotechnical investigation, aiming at the treatment of landslide phenomena particularly in seven municipalities that had suffered extensive damage.

The inquiring project titled *"Engineering Geological and Geotechnical investigation in wildfire affected Municipalities of the Ilia Prefecture for the identification and treatment of landslide phenomena – Design of landslide hazard mitigation measures"* and was supervised by the Department of Transport Works/Directorate of Public Works/Region of Western Greece.

The project was completed in September 2008 and comprised the followings:

a) Identification of all landslide phenomena and failures that occurred in the seven municipalities of the project: Amaliada, Andritsaina, Iardanos, Skillountos Oleni, Pineia, and Foloi.

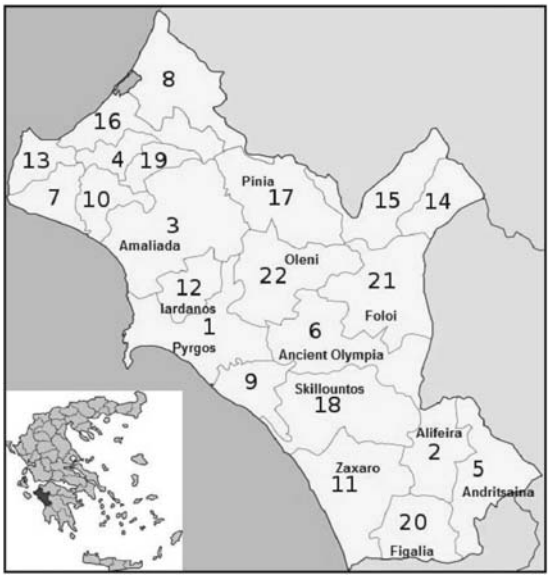

Fig. 1: Investigation area – Municipalities of the Ilia Prefecture.

b) Evaluation of landslide hazard and selection of the most serious cases for further investigation.
c) Engineering geological and geotechnical investigation of forty six (46) landslide cases that seriously affected the human environment.
d) Identification of landslide causes and trigger.
e) Production of technical reports and geotechnical maps as well as design of landslide hazard mitigation measures.
f) Submission of proposals for further investigation.

2. Investigation area

The investigation area comprised the Municipalities of Amaliada, Andritsaina, Iardanos, Pinia, Skillountos, Oleni, and Foloi (Fig. 1), occupying a total area of approximately 1115km^2. The total area of the Ilia Prefecture is 2618km^2 and the burnt land estimated to be 870km^2 (approximately 33% of the total area). The most affected Municipalities were those of the project as well as the Municipalities of Zaxaro, Alifeira, Figalia, and Ancient Olympia (Fig. 1). From the burnt land the bigger percentage included forest and agricultural land as well as residential districts. Further investigation is needed in the Municipalities of Zaxaro, Alifeira, Figaleia, and Arxaia Olympia that were not included in the inquiring project.

3. Identification of landslide phenomena in the investigation area

3.1. Landslide types and causes of movement

Zaruba and Mencl (1969, 1976) and Varnes (1978) have developed the most well known landslide classification Tables. Table 1, was adopted for landslide identification and classification during the project, illustrates a schematic landslide classification (Varnes, 1978) taking into account the modifications made by Cruden and Varnes (1996). Some integration has also been made by using the definitions of Hutchinson (1988), Coates (1977), and Hungr et al. (2001).

According to up to today studies in the Ilia Prefecture have been identified (from 1950 until

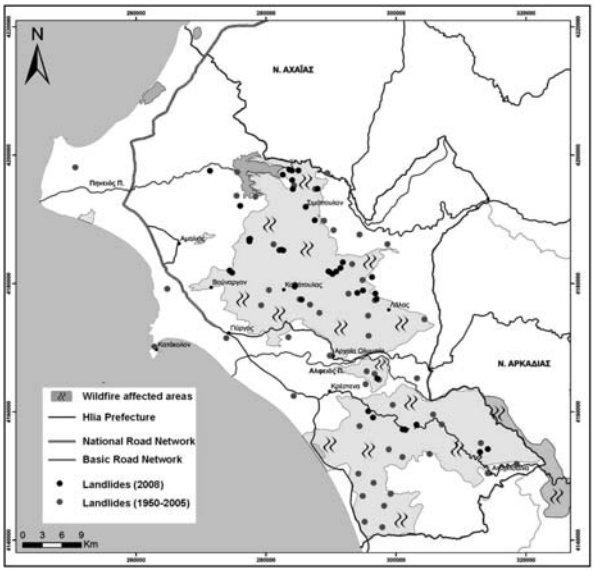

Fig. 2: Landslides identified in the Ilia Prefecture (1950-2005) & (2008).

Table 1.

Type of movement			*Type of material*		
			Bedroc	*Engineering soils*	
				Predominantly fineg	*Predominantly coarse*
Falls			Rockfall	Earth fall	Debris fall
Topples			Rock topple	Earth topple	Debris topple
Slides	*Rotationa*		Rock slump	Earth slump	Debris slump
	Translational	*Few units*	Rock block slide	Earth block slide	Debris block slide
		Many units	Rock slide	Earth slide	Debris slide
Lateral spreads			Rock spread	Earth spread	Debris spread
Flows			Rock flow	Earth flow	Debris flow
			Rock avalanche		Debris avalanche
			(Deep creep)	(Soil creep)	
Complex and compound			Combination in time or space of two or more principal types of movement		

2005) fifty eight (58) landslides (Fig. 2) of intermediate and high vulnerability. Thirty seven (37) of them (percentage 64%) are located in the investigation area, affected by the wildfires of August 2007. Therefore, many of them were expected to be reactivated with bigger intensity, because of the unfavourable conditions that prevailed after the wildfires.

During the current investigation forty six (46) landslide cases (Fig. 2) that seriously affected the human environment, of intermediate and high vulnerability, most of them existed before, were thoroughly investigated and an identification of the main types and causes of movement was made (Table 2) by using the previous landslide classification of Table 1.

Table 2.

No	*Location*	*Main types of movement*	*Main causes of movement*
	Amaliada		
1	Keramidia village	Road embankment failure/ Earth Slump and Flow	Weathering of soils/ Undercutting
2	Peristeri village road entrance	Earth Slump - Soil Creep	Weathering of soils
3	Peristeri village	Road embankment failure/ Earth Slump and Flow	Weathering of soils/ Loading
4	Peristeri Elementary school	Soil Creep	Weathering of soils
5	Provincial road Peristeri-Inoi	Road embankment failure/ Earth Slump and Flow	Weathering of soils/ Undercutting & Loading
6	North of Pinios Lake - Earth dam	Earth Slump	Undercutting & Excavation
	Andritsaina		
7	Miloi village	Rock Falls and Flow	Weathering of jointed rocks
8	Sikies village	Earth Slump	Fluvial erosion
9	Provincial road Andritsaina-Sekoulas	Debris Flow	Fluvial erosion
	Iardanos		
10	Mun. road Vounargo-Fragkopidima	Rock Falls/Earth Slides	Weathering of soft rocks/ Steep slopes & Excavation
11	Provincial road Vroxitsa-Korifi	Earth Flow	Weathering of soils
12	Provincial road Vroxitsa-Korifi	Road embankment failure	Weathering of soils
	Pinia		
13	Latta village	Earth Slump and Flow	Weathering of soils
14	Valmi village	Earth Slump	Weathering of soils
15	Municipal road Valmi-Apidoula	Earth Slides and Falls Debris Slides and Falls	Weathering of soils/ Undercutting
16	Provincial road Valmi-Xenies	Debris Slides and Falls	Weathering of soft rocks/ Steep slopes & Excavation
17	Provincial road Valmi-Agrapidoxori	Earth Falls	Weathering of soils/ Fluvial erosion
18	Agrapidoxori village road entrance	Road embankment failure/ Earth Flow	Weathering of soils/ Undercutting
19	Simopoulo village road entrance	Earth Flow	Undercutting
20	Agnanta village	Earth Slides and Flow	Weathering of soils/ Steep slopes
21	Kotrona hamlet	Soil Creep	Undercutting
22	Mazaraki village	Earth Slides and Flow	Weathering of soils
23	Kalo Paidi village	Earth Slumps and Flow Debris Slides and Flow	Weathering of soils/ Undercutting & Loading

No	*Location*	*Main types of movement*	*Main causes of movement*
	Skillountos		
24	Graika village	Earth and Debris Flow	Weathering of soils
25	Grillos cillage	Soil Creep	Weathering of soils
26	Platiana village	Rock Slides and Falls Earth and Debris Slides	Weathering of jointed rocks/Steep slopes
27	Municipal road Platiana - Archaeological site	Rock Slides and Falls Earth Slumps - Debris Falls	Weathering of jointed rocks/Steep slopes & Excavation
28	Municipal road to Tripiti	Road embankment failure/ Earth Slump and Flow	Weathering of soils/ Undercutting
29	Provincial road Krestena-Graika	Road embankment failure/ Earth Slump	Fluvial erosion/ Undercutting
30	Frixa village	Earth Slumps and Flow Earth Slides	Weathering of soils/ Fluvial erosion & Loading
31	Frixa village road entrance	Road embankment failure/ Earth Slide	Weathering of soils/ Excavation
	Oleni		
32	Rural road Goumero-Askitis	Rock Falls Earth Slides and Flow	Weathering of soft rocks/ Steep slopes & Excavation
33	Municipal road Goumero-Agia Anna (Vrisi)	Road embankment failure/ Earth Slump and Flow	Weathering of soils/ Excavation
34	Municipal road Goumero-Agia Anna (Koukos)	Road embankment failure/ Debris Slump	Weathering of soils/ Excavation
35	Goumero village road entance	Earth Slide	Weathering of soils
36	Agia Anna village	Debris Slide	Weathering of soils
37	Agios Georgios village	Earth Slide	Weathering of soft rocks/ Loading
38	Municipal road Koutsoxera-Mouzaki	Road embankment failure/ Earth Flow	Weathering of soils
39	Koutsoxera church	Earth Slide	Weathering of soft rocks/ Loading
40	Koutsoxera Primary school	Earth Flow - Soil Creep	Weathering of soils/ Loading
41	Provincial road Oleni-Magoula	Earth Slide and Flow	Weathering of soils/ Excavation
	Foloi		
42	Doukas village	Earth Slump and Flow	Weathering of soils
43	Milies village	Earth and Debris Flow	Weathering of soils/ Excavation
44	Provincial road in Avra springs	Rock and Debris Falls	Fluvial erosion/Undercutting
45	Neraida village	Rock Slides & Falls	Weathering of jointed rocks
46	Nea Persaina village	Earth Flow - Soil Creep	Weathering of soils

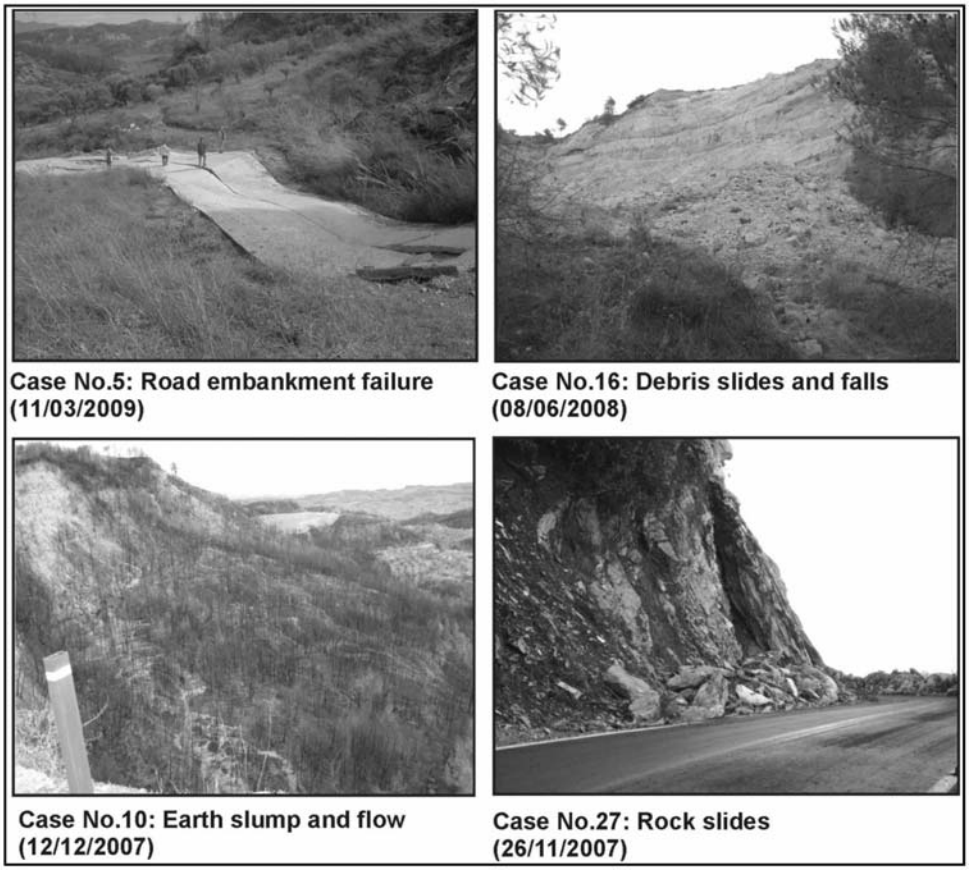

Fig. 3: Landslides identified in the Ilia Prefecture (1950-2005) & (2008).

The primary cause of movement in most of the cases of Table 2 was the loss of vertical vegetative and forestry structure after the wildfires. In shallow and poor soils the removal of deep-rooted vegetation was crucial and destabilized the already fragile slopes and as a result many landslides that existed before reactivated. The main trigger of landslide reactivation was either the intense rainfall or in some cases (7, 15, 16) a combination of rainfall and seismic activity.

Concerning the main causes of movement, according to Table 2, was the intense weathering of soils, soft rocks and hard rocks as well as:

- Excavation created by human activities mainly for the construction of roads and houses.
- Undercutting created either by human activities or physical processes.
- Loading created by human activities or excess pore water pressure after an intense rainfall
- Fluvial erosion created by rivers and streams causing loss of support on the toe of generally steep slopes or along the river/stream banks.

All landslide cases were located with precise coordinates in maps of suitable scale and the forty six (46) of them are presented in Fig. 2 along with those occurred during the period 1950-2005.

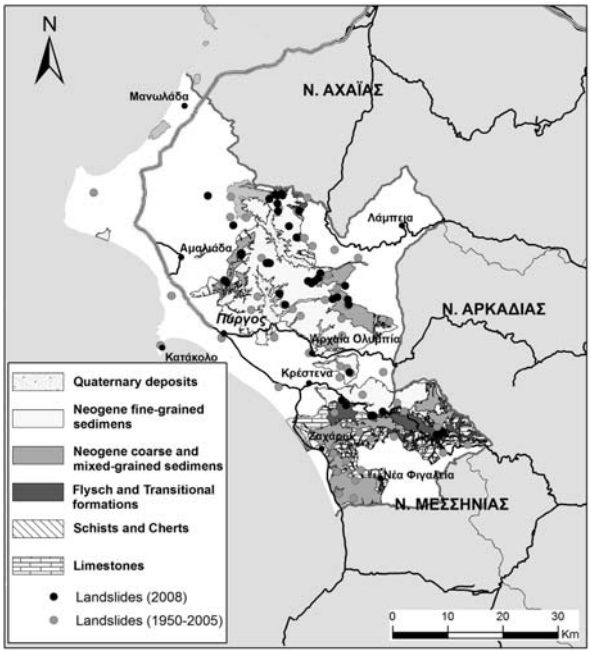

Fig. 4: Engineering Geological conditions and landslides in the Ilia Prefecture.

3.2. Effect of Engineering Geological conditions on landslide movement

The identified 46 landslide cases were occurred mainly with a complex type of movement (falls, slides, and flow) and affected by the prevailed geological formations. Earth flow, slumps, slides, and soil creeps were occurred mainly in the fine Neogenic sediments which dominate in the area. Debris slides and flow were occurred mainly in the coarse Neogenic sediments, whereas rock falls and slides as well as debris falls were activated in limestones and sandstones (Fig. 3).

All these landslides were triggered by heavy rainfall and/or seismic activity favoured by the loss of vegetation after the wildfires and the overall susceptibility of the prevailed geological formations in landsliding (Fig. 4). The geological formations of the Neogenic sediments constituted by weathered soft rocks of sandy-silt constitution, friable sandstones, and poor soils of sandy-silt constitution are prone in earth flow, slumps and slides as well as rock and debris falls and slides. In addition the jointed rocks of the limestone bedrock produce heavy rock falls and slides.

The prevailed engineering geological conditions combined with the loss of vegetation, the deforestation and the intense rainfalls contributed in the deterioration of landslide problem. However, in many cases the horizontal stratigraphy combined with the prevailed low relief produced landslides in such a scale that can be treated with protection measures economically and technically feasible provided that they will be faced in time.

4. Proposed remedial and protection measures

The proposed remedial and protection measures aiming at the treatment of landslide phenomena in the Ilia Prefecture can be summarized in the following paragraphs and Table 3:

a) Surface drainage works with the construction of surface or shallow drains, as well as diversion ditches of rain-storm waters along the road network. Surface drains includes concrete

Table 3.

No	*Location*	*Main types of movement*	*Main causes of movement*
	Amaliada		
1	Keramidia village	Road embankment failure/ Earth Slump and Flow	Drainage works/Gabion wall/ Ground improvement
2	Peristeri village road entrance	Earth Slump - Soil Creep	Surface drainage
3	Peristeri village	Road embankment failure/ Earth Slump and Flow	Drainage works/Driven-pile wall/Ground improvement
4	Peristeri Elementary school	Soil Creep	Surface drainage/Gravity wall
5	Provincial road Peristeri-Inoi	Road embankment failure/ Earth Slump and Flow	Drainage/Gabion wall/ Ground improvement/Unloading
6	North of Pinios Lake - Earth dam	Earth Slump	Surface drainage/Gabion wall/Driven-pile wall/ Rescaling
	Andritsaina		
7	Miloi village	Rock Falls and Flow	Surface drainage/Rockfall barrier/Rock scaling
8	Sikies village	Earth Slump	Drainage works/Gabion wall
9	Provincial road Andritsaina-Sekoulas	Debris Flow	Surface drainage/Gravity wall
	Iardanos		
10	Mun. road Vounargo-Fragkopidima	Rock Falls/Earth Slides	Surface drainage/Geogrids
11	Provincial road Vroxitsa-Korifi	Earth Flow	Surface drainage/Vegetation
12	Provincial road Vroxitsa-Korifi	Road embankment failure	Drainage works
	Pinia		
13	Latta village	Earth Slump and Flow	Drainage works
14	Valmi village	Earth Slump	Surface drainage
15	Municipal road Valmi-Apidoula	Earth Slides and Falls Debris Slides and Falls	Surface drainage/Gravity walls/Driven-pile wall
16	Provincial road Valmi-Xenies	Debris Slides and Falls	Surface drainage/ Gravity wall/Geogrids
17	Provincial road Valmi-Agrapidoxori	Earth Falls	Surface drainage/Geogrids
18	Agrapidoxori village road entrance	Road embankment failure/ Earth Flow	Surface drainage/ Gabion wall
19	Simopoulo village road entrance	Earth Flow	Surface drainage/Gabion wall
20	Agnanta village	Earth Slides and Flow	Surface drainage/Vegetation
21	Kotrona hamlet	Soil Creep	Surface drainage
22	Mazaraki village	Earth Slides and Flow	Surface drainage
23	Kalo Paidi village	Earth Slumps and Flow Debris Slides and Flow	Drainage works/Gabion walls/Gravity walls/Driven-pile wall

No	*Location*	*Main types of movement*	*Main causes of movement*
	Skillountos		
24	Graika village	Earth and Debris Flow	Surface drainage
25	Grillos cillage	Soil Creep	Surface drainage
26	Platiana village	Rock Slides and Falls Earth and Debris Slides	Surface drainage/Gabion wall/Rockfall barrier/Rock scaling
27	Municipal road Platiana - Archaeological site	Rock Slides and Falls Earth Slumps - Debris Falls	Surface drainage/Gabion wall Gravity walls/Unloading
28	Municipal road to Tripiti	Road embankment failure/ Earth Slump and Flow	Surface drainage/ Gabion wall
29	Provincial road Krestena-Graika	Road embankment failure/ Earth Slump	Surface drainage/ Gabion wall
30	Frixa village	Earth Slumps and Flow Earth Slides	Moving of population
31	Frixa village road entrance	Road embankment failure/ Earth Slide	Surface drainage/Gabion wall/ Ground improvement
	Oleni		
32	Rural road Goumero-Askitis	Rock Falls Earth Slides and Flow	Surface drainage/Unloading/Rock scaling
33	Municipal road Goumero-Agia Anna (Vrisi)	Road embankment failure/ Earth Slump and Flow	Drainage works/Gabion wall
34	Municipal road Goumero-Agia Anna (Koukos)	Road embankment failure/ Debris Slump	Surface drainage
35	Goumero village road entance	Earth Slide	Surface drainage
36	Agia Anna village	Debris Slide	Rescaling
37	Agios Georgios village	Earth Slide	Surface drainage/Ground improvement
38	Municipal road Koutsoxera-Mouzaki	Road embankment failure/ Earth Flow	Surface drainage/Ground improvement
39	Koutsoxera church	Earth Slide	Gravity wall
40	Koutsoxera Primary school	Earth Flow - Soil Creep	Drainage works/Gabion walls
41	Provincial road Oleni-Magoula	Earth Slide and Flow	Surface drainage/Gabion wall
	Foloi		
42	Doukas village	Earth Slump and Flow	Surface drainage
43	Milies village	Earth and Debris Flow	Surface drainage/Vegetation
44	Provincial road in Avra springs	Rock and Debris Falls	Rock scaling/Gabion wall/ Suspended netting
45	Neraida village	Rock Slides & Falls	Rockfall barrier
46	Nea Persaina village	Earth Flow - Soil Creep	Surface drainage

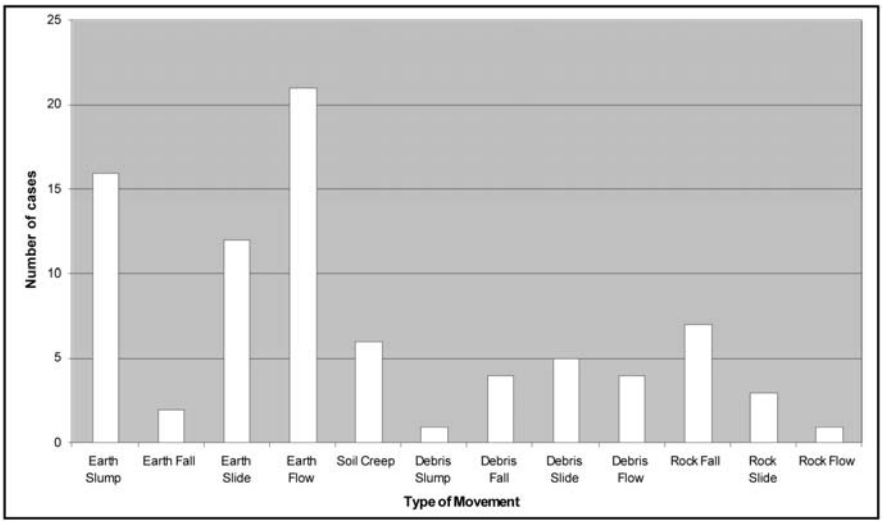

Fig. 5: Main types of landslide movement.

diversion ditches, whereas shallow-interception drains includes perforated tubes covered by granular material in trenches up to 2m deep lined with geotextiles.

b) Subsurface drainage works with the construction of drainage trenches up to 3m deep and 1m wide, as well as drainage blankets up to 1m thick on top of the base of road embankments in order to reduce water infiltration and divert quickly subsurface water away of the problem.

c) Construction of retaining walls, usually concrete gravity walls and gabion walls. Gravity walls were proposed to be constructed on small slopes or small parts of large slopes in cases of solid ground. Gabion walls were proposed in cases of small slopes and road embankments as toe weight. **Driven pile-walls** were proposed to be constructed in cases of deep slide problems.

d) Rockfall barriers were proposed for construction in cases 7, 25, 45, where steep rocky slopes of a great height prone to rock falls and slides were existed, in order to protect residential areas.

e) Ground improvement which includes development of vegetation, geotextiles, geogrids in soil slopes or road embankments that have failed due to poor substratum conditions. Vegetation cover was proposed to reduce water infiltration and provide tensile strength in surface layers. Anchored geotextiles or geogrids were proposed in cases to fix fragile surface slopes and allow plant growth.

f) Slope modification by unloading or rescaling soil slopes and scaling rock slopes.

5. Conclusions

All landslide cases activated or reactivated mainly with a complex type of movement (Fig. 5). Earth flow, slumps, slides, and soil creeps were occurred in the fine Neogenic sediments. Debris slides and flow were occurred in the coarse Neogenic sediments, whereas rock falls and slides as well as debris falls were activated in limestones and sandstones.

All landslides were triggered by heavy rainfall and/or seismic activity. The prevailed engineering geological conditions combined with the loss of vegetation, the deforestation, the in-

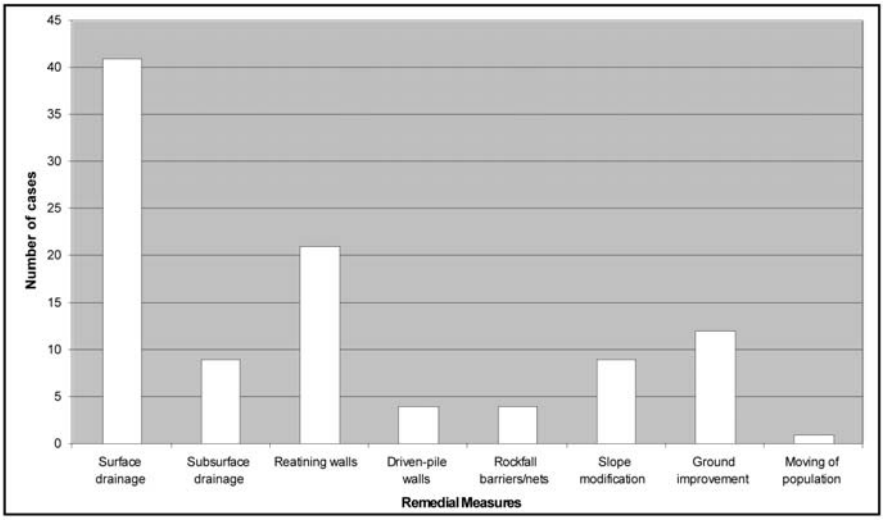

Fig. 6: Remedial and protection measures of landslide cases.

creased weathering and the intense rainfalls contributed in the deterioration of landslide problem. Human activities and fluvial erosion in some cases increased the landslide problem.

All remedial and protection measures proposed for landslide treatment are illustrated in Fig. 6 and mainly include surface and subsurface drainage works combined in many cases with the construction of retaining walls. The other main type of remedial works includes ground improvement and rockfall barriers for the protection of residential areas.

6. Acknowledgments

The work was carried out under the support of the Region of Western Greece. The authors wish to express their sincere appreciation to its generous support.

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